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Waste cathode rays tube: an assessment of global demand for processing

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Abstract

The management of used Cathode rays tube (CRT) devices is a major problem worldwide due to rapid uptake of the technology and early obsolescence of CRT devices, which is considered an environment hazard if disposed improperly. Previously, their production has grown in step with computer and television demand but later on with rapid technological change; TVs and computer screens has been replaced by new products such as Liquid Crystal Displays (LCDs) and Plasma Display Panel (PDPs). This change creates a large volume of waste stream of obsolete CRTs waste in developed countries and developing countries will become major CRTs waste producers in the forthcoming decades. This article provides a concise overview of world's current CRTs waste scenario, namely magnitude of the demand and processing, current disposal and recycling operations.

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Keywords: Cathode Rays Tube; E-waste; Recycling; Solutions.

1. Introduction

Since the 1950s, CRTs have been used in television and computer screens. Historically, their production has grown in step with television and computer demand. In 2001, the global CRT monitor industry was valued at US $19.5 billion, producing 108 million units [1]. However, at present, CRT technology for televisions and computers is obsolete, the market for new CRTs is dwindling and CRT production in the world is limited now [2]. That is because it is an old and highly energy consumptive technology, which is now being replaced by new technologies; like LCDs

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and PDPs but in the most part of Asia-Pacific, Eastern Europe, Middle East and Africa, which are regarded as emerging regions for technology still there is demand for CRT TVs and monitors by low-income consumers because CRT sets are the cheapest option compare to expensive LCD TV sets [3]. Meanwhile, it is also clear that, even for those markets, CRTs will eventually be supplanted [4].

In case of developed nations, at least, it is now impossible to find a CRT computer monitor or television in electronic shops. However, they are still present in the houses of many people, and gradually being replaced by new flat screens [5]. According to WEEE collection and pre-treatment market, about 50,000–150,000 tons/year of end of life CRTs are currently collected within Europe and this flux is not expected to decrease in the next years [6]. Similar in the United State, an analysis of the demand for CRT glass in the United States has discovered that CRTs comprise the largest portion (estimated by U.S. EPA at 43 percent) of the current e-waste stream and significant quantities (6.9 million tons or 232 million units) of CRTs remain to be recovered from homes and businesses in the U.S. The vast majority of these CRTs (85 percent) are projected to be collected and require management over the next 10 years. An additional 330,000 tons (or 12,000,000 units) has reported to be currently stockpiled by processors [2]. The situation is quite similar in Asian country as well for instance in China, in 2012 it is estimated that 190 million personal computers and 74 million televisions will become obsolete [7] and also in 2010, the recycling and dismantling number of waste electrical appliances through "Old for new" policy is 3344.6 million, in which 80% are CRT monitor [8].

Apart from the domestic production of the CRT waste in developing countries, it is also having even Trans boundary movement of CRT waste from developed countries. For example, an independent enquiry carried out by a branch of the US government to find out the widespread distribution of CRTs to the black market by recycling companies [7]. In addition to remote transactions via websites, buyers from developing countries, particularly African countries, are also known to travel to OECD countries as "waste tourists" to secure supplies of e-waste and arrange shipment [9].

Despite all these problems, the management of waste CRT will be required whether through direct re-use, reclamation, resource recovery, and recycling or disposal operations. The recycling of CRT waste is not feasible as economically because of their toxicity and also have few limited reuse options [10]. Whereas, an emerging factor that creates incentives for recycling of CRT waste is the demand of Lead and its higher price. Therefore, the recycling and recovery market becomes an important element impacting both the legal and illegal trans-boundary movement of e-waste worldwide.

The disposal of television and computers is a unique issue due to the fact that most television and computers are often disposed of before they truly become useless. In fact, the main reason for purchasing a new computer is not to replace a non-functioning system, but to keep up with rapidly changing technologies [11]. Additionally, the progressive replacement of old CRT TV and PC screen with LCD or PDPs has creates a large volume of waste stream of obsolete CRTs waste around the world which may going to be cause huge amounts of glasses to be landfilled [12].

Various reports within the past year have been indicated that some processors are stockpiling CRTs specifically in the developed countries due to a lack of market capacity or affordable access to market capacity. Other processors are reporting concerns about the ability to continue securing markets for CRT glass. These market constraints are a concern given the high levels of lead in CRT glass and the continued interest in ensuring the viability of the e-waste recycling industry [2]. This article provides a concise overview of world's current CRTs waste scenario, namely magnitude of production and processing, current disposal and recycling operations.

2. Characteristics of waste CRT

A cathode ray tube or CRT is a specialized vacuum tube in which images are produced when an electron beam strikes a phosphorescent surface. Besides television sets, cathode ray tubes are used in computer monitors, automated teller machines, video game machines, video cameras, oscilloscopes and radar displays. There are two types of CRT: black and white (monochrome) and colour. In general CRT consists of a front panel used as the screen, a neck, which envelops the electron gun, and funnel, which connects the panel and the neck. It is estimated that CRT constitutes around 65% of the weight of a television or a computer monitor and is composed of 85% glass of which

the front panel contributes 65%, funnel 30% and neck glass 5% [6, 13]. Figure 1. Describes below the functional components of a typical CRT [13].

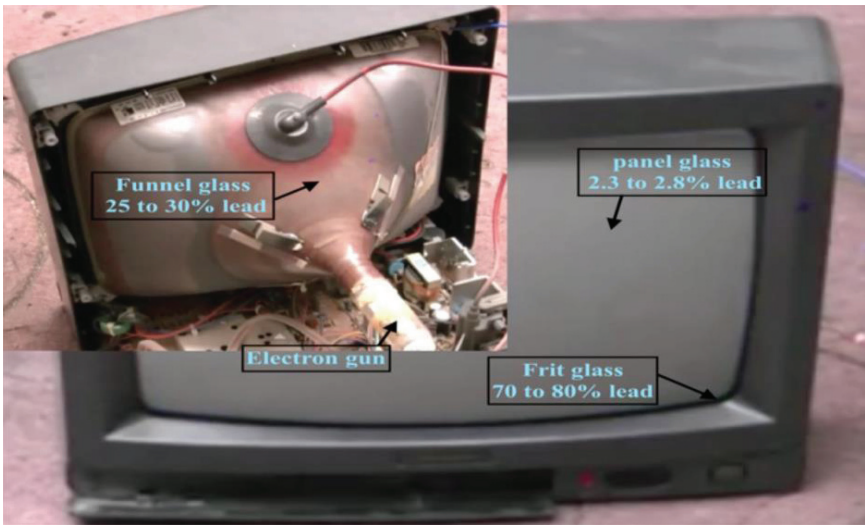

Figure 1. A schematic view and Components of Cathode Rays Tube

From the chemical analysis of glass that notably influence their properties has shown in Table 1 [6, 14, 15] and the presence of lead oxide is associated to the X-ray shielding ability required for the glass to prevent the dispersion.

Table 1. Chemical analysis (oxide wt. %) of black & white and color CRT glasses

Oxide	TV + PC panel		TV + PC funnel		Neck	
	B&W	Colour	B&W	Colour	B&W	Colour
SiO_2	66.05	61.23	65.49	56.72	56.5	50.00
Al_2O_3	4.36	2.56	4.38	3.42	1.00	1.00
Na_2O	7.63	8.27	7.05	6.99	4.00	2.00
K_2O	6.65	5.56	5.72	5.37	9.00	10.0
CaO	0.00	1.13	0.00	3.12	0.00	2.00
MgO	0.01	0.76	0.00	2.02	0.00	0.00
BaO	11.38	10.03	11.2	4.03	0.00	0.00
SrO	0.99	8.84	0.94	1.99	0.00	0.00
Sb_2O_3	0.44	0.10	0.44	0.11	0.40	0.00
Fe_2O_3	0.25	0.30	0.14	0.30	0.00	0.30
CoO	0.01	0.02	0.01	0.00	0.00	0.00
TiO_2	0.13	0.35	0.03	0.19	0.00	0.00
ZrO_2	0.07	0.91	0.01	0.24	0.00	0.00
ZnO	0.00	0.18	0.00	0.22	0.00	0.00
PbO	0.03	0.02	0.00	15.58	29.0	34.0
NiO	0.04	0.03	0.03	0.02	0.00	0.00
Others	1.96	-	3.56	-	0.00	-
Total	100	100	100	100	100	100

In addition, the inside of the CRT panel is coated with layers of phosphor, which may also contain cadmium and other metals. The outer section of the funnel section is coated with graphite and inner section with iron oxide [14-16].

3. Global Generation of CRT Devices

The worldwide market for CRT has been downgraded to 32 million units on declining demand and waning supply of core components. This is evidenced by the market figures presented in Table 2, which shows the worldwide market for CRT and LCD desktop displays in 1998, 2002 and in 2010 [17-19].

Table 2. Desktop displays in the worldwide market (millions)

Technology	1998	2002	2010	2015
CRT	80.7	83.3	218	250
LCD	1.3	32.2	32.0	5.0
Total	82.0	115.5	250	255

According to the United Nation University, the global quantity of CRT screen waste generation of in 2014 was around 6.3 Mt [20]. Most of the screen waste was generated in Asia: 2.5 Mt in 2014, followed by the highest screen waste generation in absolute quantities are Europe (1.7 Mt), America (1.7 Mt), Africa (0.3 Mt) and Oceania (0.1 Mt).

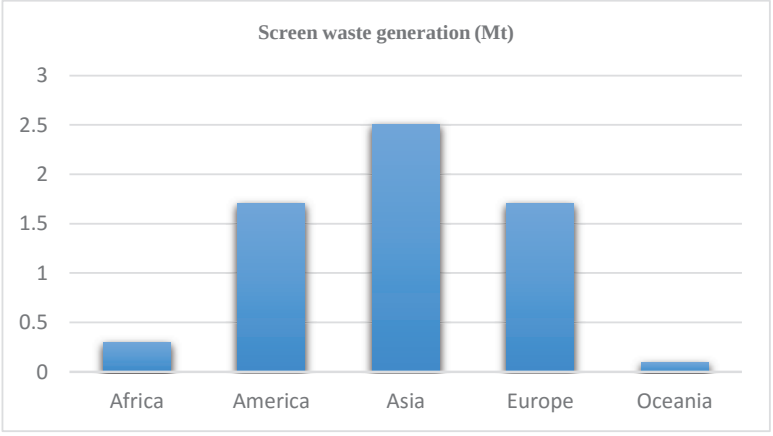

Figure 2. Global monitor screen waste generated in 2014. Data source from [20].

Although, the millions of TVs and computers purchased around the world every year (183 million in 2004) become obsolete they leave behind lead, cadmium, mercury and other hazardous wastes. Over the past two decades, the global market of EEE continues to grow exponentially, while the lifespan of those products becomes shorter and shorter. In the United States (US) market, in 2006, more than 34 million TVs have been exposed in the market, and roughly 24 million PCs and 139 million portable communication devices have been produced. In the European Union, waste electrical and electronic equipment represents about 7.5 million tons each year, where computer monitors and TV sets containing cathode ray tubes (CRTs) represent about 80% of the total electronic waste [1, 2].

Countries in Asia have been at the forefront of the production of CRT-containing devices. For example, China manufactures approximately 90% of the global CRT production [21]. The statistical data are presented in Fig. 2 [22].

The figure shows that the number of TV sets produced in China has grown rapidly since 2000 to 2012 and at present China is the largest producer and exporter of TV sets in the world.

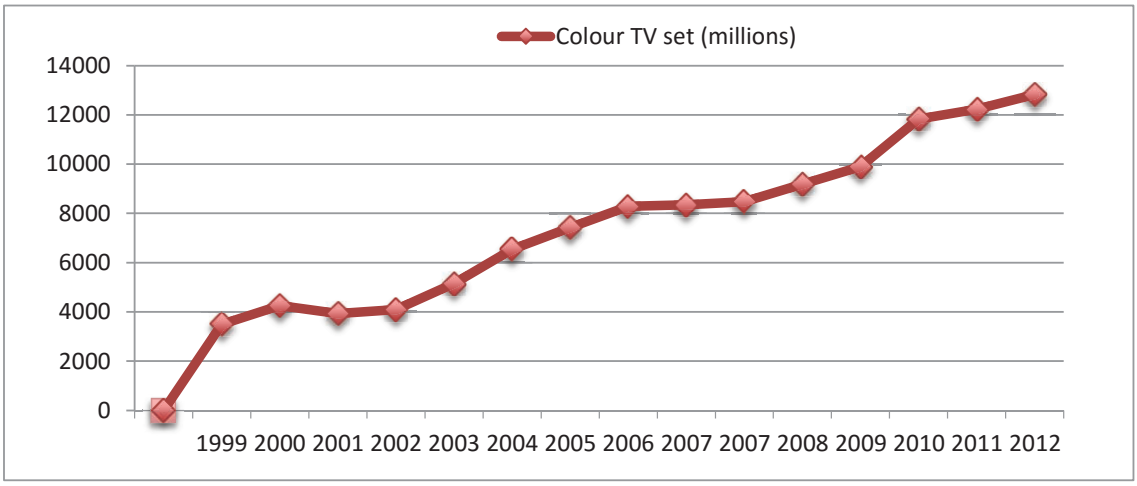

Figure 3. An overview of color TV production in China. (China Statistical Yearbooks 2013)

Table 3, shows the quantities put on the market, stock or installed base and the quantities of computer monitors and TVs waste generated in 11 different countries, from the different product groups which were selected according to available country assessments has been estimated by S. Innovation (2009) UNEP [23].

Table 3 Quantities put on the market, stock or installed base, computer monitors and TVs waste

Countries	Quantity put on the market		Stock (installed base)		Quantity of PCs & TVs generated	
	PCs	TVs	PCs	TVs	PCs	TVs
S. Africa	32000	35800	99200	189900	19400	23700
Kenya	5 200	-	21300	22600	2500	2800
Uganda	700	-	7500	15600	1300	1900
Morocco	15100	16800	67500	151000	13500	15100
Senegal	1100	4200	3100	15000	900	1900
Peru	7000	-	70000	92300	6000	11500
Colombia	13600	-	57300	146400	6500	18300
Mexico	63700	224100	300000	750000	47500	166500
Brazil	-	-	483800	1 096000	96800	137000
India	140800	450000	425000	1 904600	56300	275000
China	419100	1170000	1 324800	11 975300	300000	1 350000

Over the recent past, the CRTs collected for recycling were recycled into new CRTs through glass-to-glass recycling, or else sent to secondary lead smelters to recover the lead. Glass-to-glass recycling has been the most common management method but at present there are no more option for glass-to-glass recycling specially since its being replaced by new technologies [2]. Furthermore, owing to their different chemical compositions, CRT glass cullet must generally be separated into panel and funnel glass to be used extensively in the production of new CRTs [24, 25]. Several barriers exist to increasing the recovery of CRT cullet. First, the lead in the glass precludes its use in high volume glass products such as containers or windows. The lead content can also lead to the glass being classified as a hazardous material; overall these factors mean that CRT glass has relatively low value. This creates

situations where the materials in an End of Life TV or monitor are worth less than the cost to recover that material [25]. In fact, depending on the degree to which the glass has been separated and cleaned, processors will often have to pay a downstream recipient to accept the cullet.

Alternative applications for secondary CRT glass have been proposed including bricks, decorative tile, nuclear waste encapsulation, construction aggregates, fluxing agent, and sandblasting medium [26, 27] Several projects are working to reduce the barriers to use in these applications, nevertheless, in all cases identified to-date secondary CRT glass substitutes only for other low cost materials [24]. Gregory et al. (2009) investigated the weight of CRT glass cullet generated and the amount of CRT glass collected in each region as it evolves over time. Figure 1 and 2 show these amounts for the four regions in 2010 and 2020 (weights are in metric tons, as in all plots) [4].

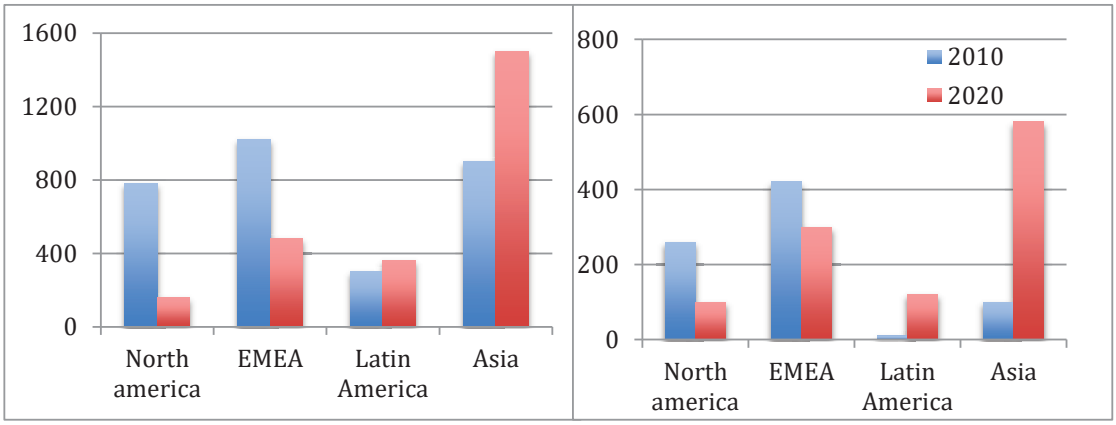

Figure 4. Weight of CRT glass cullet generated and collected in the four regions in 2010 and 2020

4. Difficulties for Recycling waste CRTs

The CRT is made of several different glass components with different chemical composition and properties. The glass components of a CRT are classified into four with each containing differing quantities of Pb in different chemical and physical forms. Hence, not knowing the exact composition of the recycled glass is one of the main barriers to recycling. In addition, there are further barriers for recycling waste CRT glass at local level as described below [6, 17, 28];

- Open-loop recycling is a difficult process (compared to closed-loop) as it is difficult to use waste CRT glass which may contain elements such as lead and cadmium in products such as glass containers, table-ware, or glass fibres.
- The presence of barium and strontium are not welcomed by glass fibre manufacturers even with encouraging experimental evidence. The inner surface of the panel glass is coated with different layers which consist of different types of heavy metals and hazardous substances. For example, the fluorescent powder coating used in color CRTs contains cadmium and phosphorus. These materials hinder the recycling of CRT glass.
- The recycling technologies for ordinary bottle glass is readily available compared to recycling technology for CRT glass and collection infrastructure for the ordinary glass is well established worldwide. This has resulted in a surplus supply of recycled glass for ordinary glass manufacturing industry.
- The recycling infrastructure for scarp televisions and computer monitors is not well established in many countries resulting in low generation of scarp CRT glass.

The perceived challenges/barriers in the effective management of end of life CRTs at the global level have been previously highlighted by [29] as follows:

- *Export:* Trans-boundary movement of large quantities of non-functional CRT containing devices from developed countries into less developed countries, which results from the lack of distinction between used electronic products and waste electronic products [9]
- *Toxicity:* Studies have indicated that CRTs consistently failed tests used in the characterization of solid wastes as toxic. In addition, the inner surface of the panel glass is coated with different layers which consist of different types of heavy metals and hazardous substances. For example, the fluorescent powder coating used in colour CRTs contains cadmium and phosphorus, and these materials hinder the recycling of CRT glass;
- *Technological advancement:* The coming new display technologies, LCDs and plasma display panel (PDP) screens has seen the replacement of CRT screens, and subsequently the reduction in production of CRT and as well as the reuse of recycled CRT glass in CRT manufacturing;
- *Recycling:* Recycling infrastructure for waste CRTs is grossly inadequate or absent even in the developed countries. Where available, recycling has, in most cases, been uneconomical with highly toxic residues generated. Similarly, the recycling infrastructure for scrap TVs and obsolete computer monitors is not well established in many countries, resulting in low recycling of scrap CRT glass;
- *Reuse of recycled material:* Few reuse options are available for recycled materials. Some CRT manufacturers may not readily opt for the recycled glass to avoid contamination (because of inconsistencies in the quality of the recovered material). Similarly, the recycled glass hardly finds alternative uses because of Pb contamination.

5. State of the art for CRT Recycling Technology

The recycling of CRT waste is a critical step in the recycling of electronic waste. The CRT monitor is the largest and heaviest component of a computer, it's composition is basically Leaded glass and the fact that it is a hazardous residue makes the CRT monitor of low interest to e-waste recycling companies [28]. In WEEE recycling companies, the CRT recycling circuit starts with the collection, temporary storage and cleaning of monitors. The problem with collection and storage is that CRT monitors are considered hazardous residue, so its transportation and storage most comply with all the regulations of hazardous waste management. The dismantling of CRT components is the next step. The CRT monitor is manually opened and its components are removed one by one. The CRT is kept intact, without the metallic band and any polymeric adhesive on its surface. The other CRT components follow the conventional recycling systems. Polymers are crushed and sent to recycling companies, metals are sent to smelter companies and the printed circuit boards follow the viable recycling route.

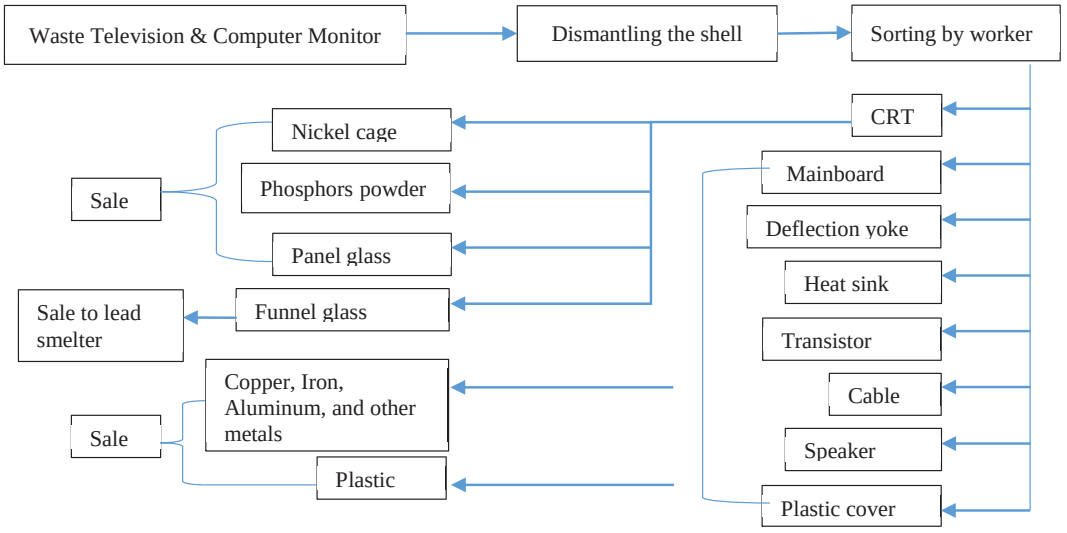

Figure 5. Recycling processes and material flows of waste CRT monitors.

5.1. CRT Recycling System

The recycling of CRTs is based on closed-loop and open-loop recycling systems. The closed-loop system refers to the recycling of CRTs in the manufacturing chain itself. Here, the old tubes are used in the manufacturing of new CRT tubes [30]. In closed-loop recycling, the entire CRT glass is ground into cullets without separation of panel and funnel glass [31]. This approach was feasible when CRT productions dominated the market and it was considered the "Best Available Technology" due to its effectiveness at that time [32]. However, since the demand for new CRTs is now on the decrease as a result of their replacement by new display technologies which consume less energy and are more popular among consumers, the demand for CRT displays has dropped substantially [33, 34]. Similarly, the presence of graphite coatings (carbon slurry, graphite and fluorescent colours) in the inside of CRTs is thought to be undesirable in glass manufacturing because it interferes with the glass melting process associated with the closed-loop systems, which lowers the quality of the glass [32]. For these reasons, waste CRTs will have to be managed differently.

The open-loop system involves the recycling of CRT glass in the manufacture of new products. however, it is often difficult to provide raw CRT glass of tightly controlled quality due to variation in its composition, which is still being treated as a trade secret by manufacturers [35] and understanding the composition of CRT glass is very important if it is to be utilized in this application [32]. Hence, recycling CRT glass in these products could become an obstacle due to compositional differences between CRT glass and other glass products [16, 36]. Although, the use of CRT glasses in these applications may be efficient only if the leachability of heavy metals do not exceed regulatory limits [37]. Considering this outlet will limit its use to the panel glass because it possesses a relatively constant composition and low/no Pb content.

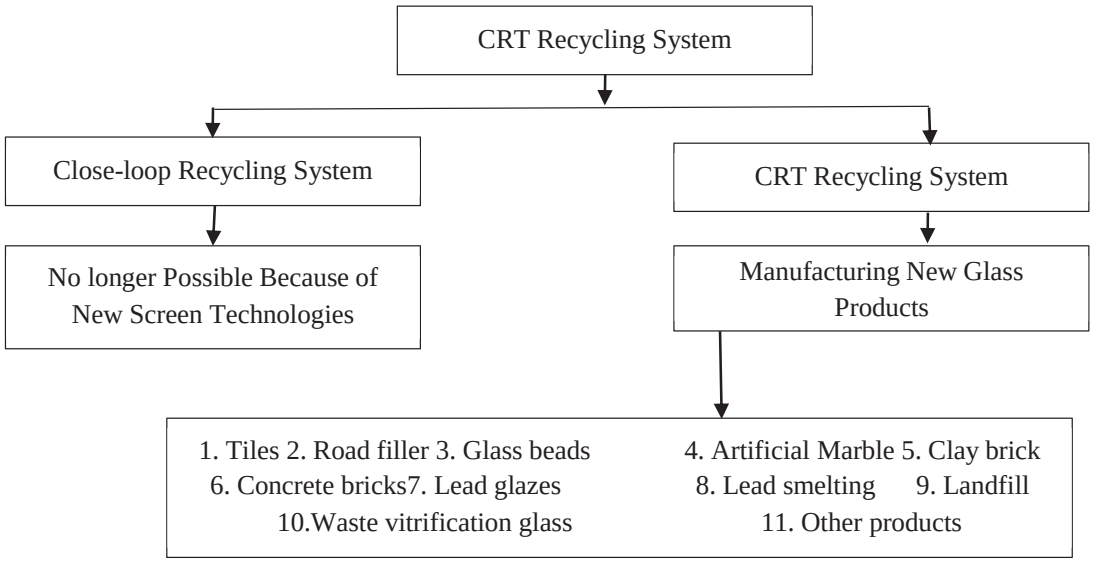

Figure 6. A systematic overview of CRT recycling system

6. Conclusion and Recommendation

CRTs waste is universal. The data reported in this paper highlights the need for CRT glass manufacturers, recyclers, state and federal regulators and the public to work together to find a use for the increased volume of CRT

cullet so it can be recycled into new products, including, but not limited to, new CRTs. Industry and government also need to find ways to promote the development of technology needed to allow recyclers to more accurately classify CRT cullet. With better classification and sorting technology, the amount of CRT cullet the CRT glass manufacturers could recycle could increase dramatically.

Some ideas for new technologies exist but a great deal of work needs to be done to develop new technologies that are environmentally and economically feasible and widely available. Finally, in developing countries, the study recommends that the Glass-to- Glass Rule reduce regulatory burdens on CRT glass destined for both glass-to-glass recycling and recycling into products and processes other than CRT glass. This would provide economic incentive for other legitimate recycling efforts that could absorb some of the CRT glass that the CRT glass manufacturers cannot reuse.

Acknowledgements

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